Matching optical parameters while injecting the proton beam to the Tevatron

activity report

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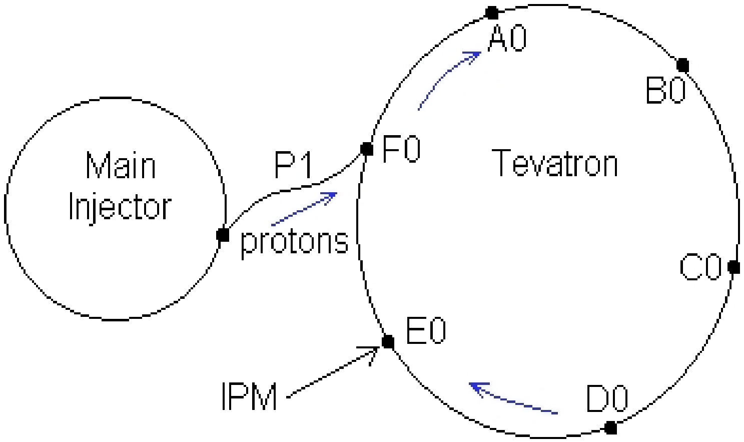
Talk outline

- Beam size oscillations in the Tevatron after injection and emittance growth
- How can betatron and dispersion mismatch affect beam size oscillations? (simple simulation of beam size oscillations)
- Measurement of dispersion mismatch using BPMs and estimation of the influence of this mismatch
- Tools for controlling the betatron mismatch
- Plans to measure betatron mismatch using IPM and control the mismatch in order to decrease oscillations

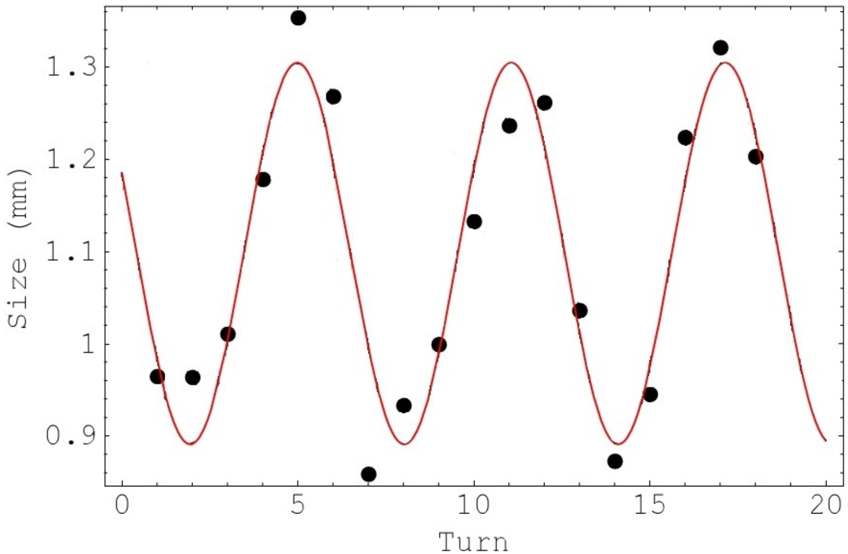
Beam size oscillations

- We have data about turn-by-turn beam size oscillations. Measurements were made at injection of protons from Main Injector to the Tevatron through transfer line P1.
- We assume that the oscillations are caused by betatron and dispersion mismatch when injecting.
- The effect yields beam size oscillations of ±20%. This should result in emittance blow-up of 10% due to spreading beam on phase plane.
- As result, we obtain corresponding loss of luminosity of about 10% since luminosity is inversely related to beam size.

$$L=\frac{N^2\cdot f_0}{2\pi\cdot\sigma_x\cdot\sigma_y}$$



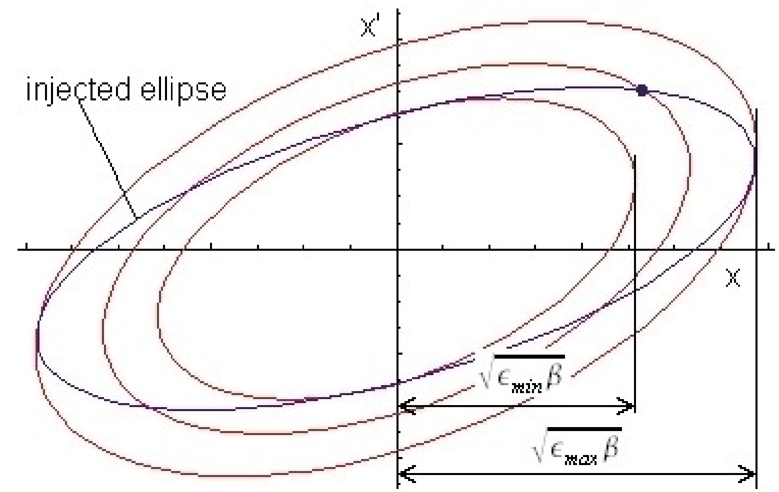
Facility diagram demonstrating injection of proton beam.



Vertical turn-by-turn data obtained with help of IPM. Red line is a fit by sine-like function.

Betatron mismatch influence

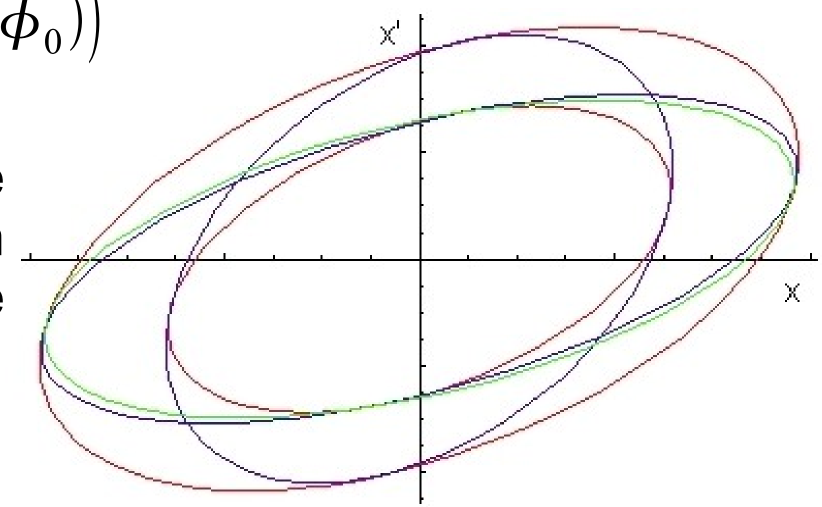
Let's consider the beam injected to the ring with betatron mismatch (blue ellipse)



Each injected particle will move along own ellipse, one of set of ellipses (red ellipses) with certain α, β – parameters according to

$$x=\sqrt{\epsilon\,\beta(s)}\cdot\cos(\mu(s)+\phi_0)$$

$$x'=-\sqrt{\frac{\epsilon}{\beta(s)}}\cdot\left(\sin(\mu(s)+\phi_0)+\alpha(s)\cdot\cos(\mu(s)+\phi_0)\right)$$

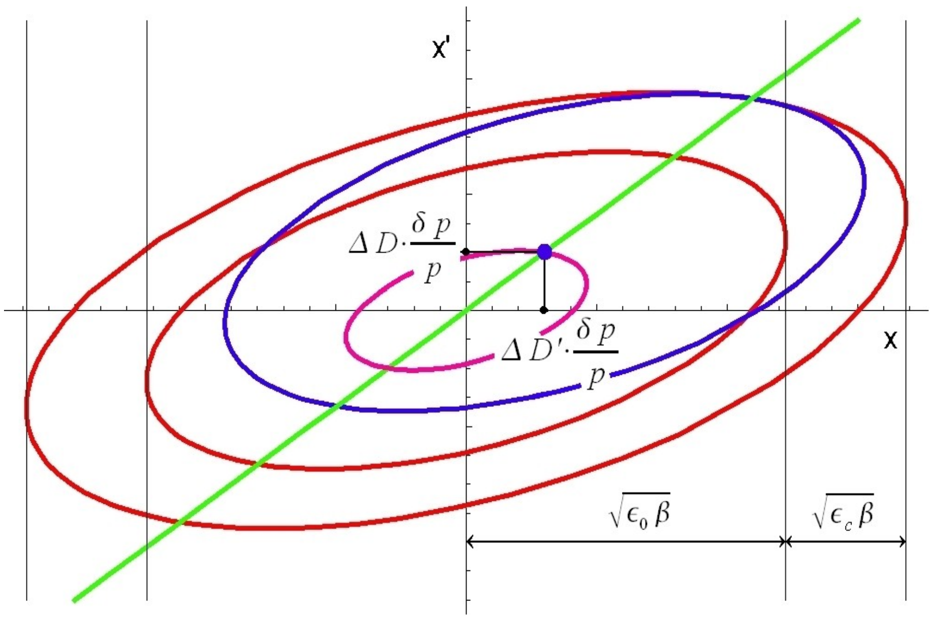


We will observe rotation of blue ellipse concerning the center. Size of beam (projection of ellipse to x axis) will oscillate with twice betatron tune.

$$\mu=2\pi\cdot\nu\cdot n \qquad a=\sqrt{\beta\cdot\epsilon}$$

$$\epsilon=\epsilon_0\cdot[1+\frac{\delta\beta}{\beta}\cos(2\mu)+(\alpha\frac{\delta\beta}{\beta}-\delta\alpha)\sin(2\mu)]$$

Dispersion mismatch influence



Oscillations of ellipse injected with dispersion mismatch. The center of ellipse moves along pink ellipse. This picture shows that beam size will oscillate with twice betatron frequency.

Consider the bunch injected with energy deviation and dispersion mismatch to the ring. The center of injected ellipse on the phase plane will be deflected as shown on the picture and can be expressed as following

$$x_c = \Delta D \cdot \frac{\delta p}{p} \qquad x_c' = \Delta D' \cdot \frac{\delta p}{p}$$

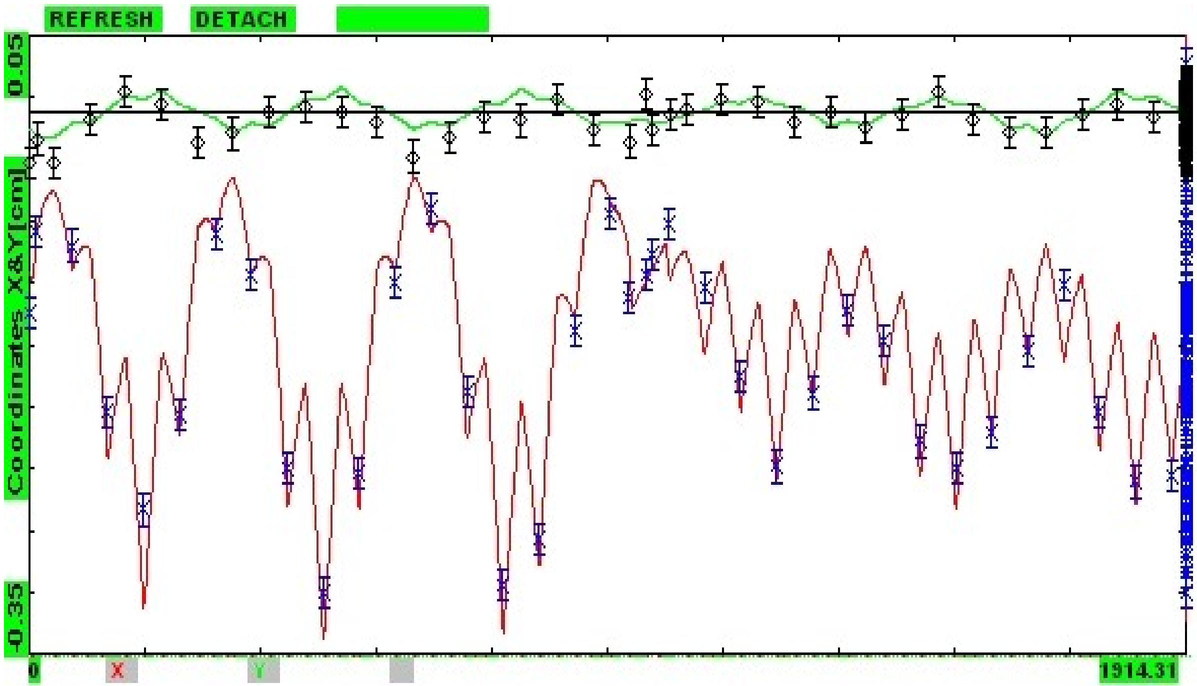
We can calculate parameters of ellipse along which the center will move. Amplitude of beam size oscillations is determined by projection this ellipse on X-axis in the following way

$$a = \sqrt{\beta \cdot \epsilon_c}$$

$$\epsilon_c = \frac{1}{\beta}\left((\Delta D)^2 + (\alpha \cdot \Delta D + \beta \cdot \Delta D')^2 \right) \cdot \left(\frac{\delta p}{p} \right)^2$$

The last formula can be used in order to estimate emittance blow-up due to dispersion mismatch

Measurement of dispersion mismatch



BPM (beam position monitor) was used for dispersion mismatch measurements. The beam with deviated energy was injected to the Tevatron and beam position on the first turn was measured for different points along the lattice. Good match with lattice dispersion function multiplied by momentum deviation demonstrates that dispersion mismatch does not exceed measurement error.

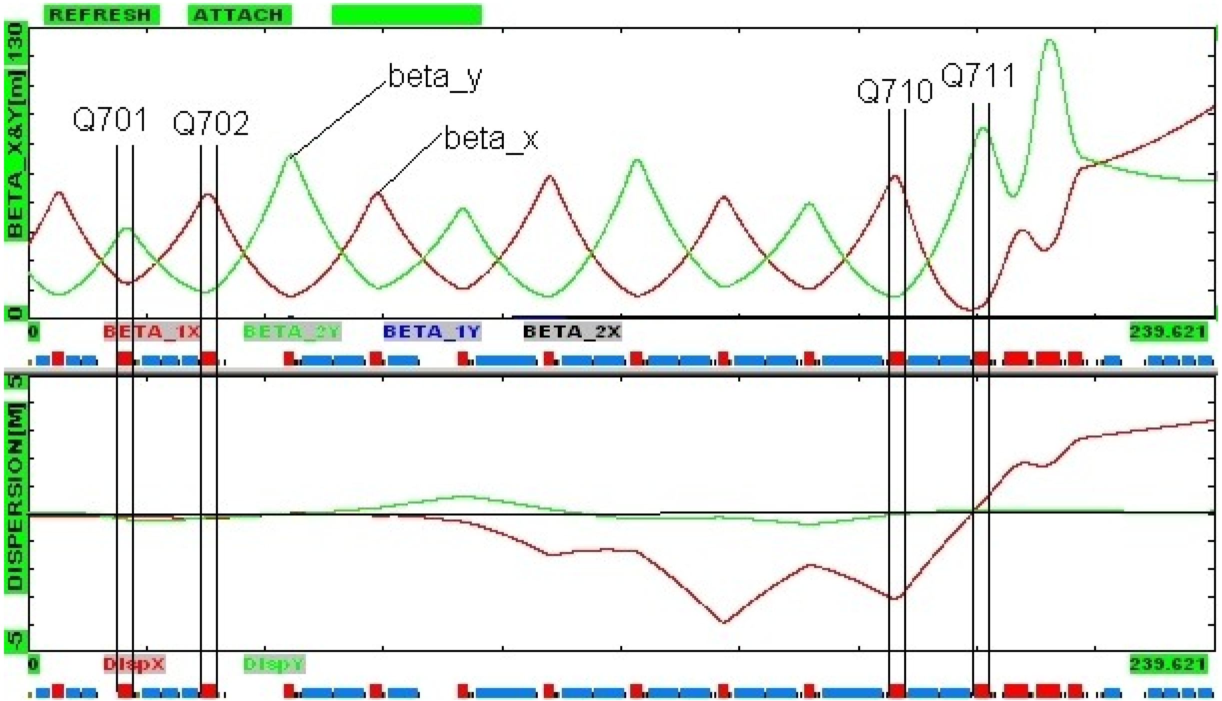
Let's estimate emittance growth knowing energy spread in the beam

$$\Delta \epsilon = \frac{1}{\beta}\left((\Delta D)^2 + (\alpha \cdot \Delta D + \beta \cdot \Delta D')^2 \right) \cdot \frac{\sigma_p^2}{2}$$

It leads to rough over-estimate $\frac{\Delta \epsilon}{\epsilon} < 0.01$

It's seen that dispersion mismatch sufficiently small. We can finish to consider dispersion mismatch and advert to controlling betatron mismatch which plays dominant role.

Controlling betatron mismatch



One can see the optic properties of the transfer line P1 on the picture.

We can use quadrupoles to control injection beta-functions.

We have 4 parameters at injection and we need to use 4 tools.

There are a few reasons to use the quadrupoles denoted on the picture

- <u>validity of thin lens approximation</u>
- <u>independent current controlling</u>
- <u>good phase advance</u>

$$\frac{\Delta \beta_m}{\beta_m} = \beta_c \cdot \sin(2(\mu_m - \mu_c)) \cdot (\delta k l)$$

$$\left(\alpha_m \frac{\Delta \beta_m}{\beta_m} - \Delta \alpha_m\right) = \beta_c \cdot \cos(2(\mu_m - \mu_c)) \cdot (\delta k l)$$

<u>Response matrix was created</u> by using optical functions, such as alpha, beta functions and phases in the certain points. It allows to calculate necessary quadrupole changes in order to match injection parameters.

Resume!

What has been done?

- obtained and checked the formulas simulating beam size oscillations
- made measurement studies demonstrating smallness of dispersion mismatch
- transfer line was studied to control optical parameters
- developed idea how to measure betatron mismatch with help of IPM

What are we going to do in the near future?

- make measurement of turn-by-turn beam size data using IPM
- determine necessary changes of quadrupole currents
- control the mismatch to increase luminosity

Thank you for your attention!

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